

APPLICATION FOR UNITED STATES PATENT

FUEL COMPOSITION SUPPLY MEANS FOR DRIVING  
CYCLE CONDITIONS IN SPARK IGNITION ENGINES

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FUEL COMPOSITION SUPPLY MEANS FOR DRIVING  
CYCLE CONDITIONS IN SPARK IGNITION ENGINES

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[0001] This application is a Continuation-In-Part of U.S. Serial No. 09/818,203  
filed March 27, 2001 which is based on Patent Memorandum 00CL090

10 FIELD OF INVENTION

[0002] The present invention relates generally to a means for supplying engine  
fuel compositions and their use in spark ignition, internal combustion engines  
especially those having a compression ratio (CR) of 11 or more. The engine fuel  
15 supply is tailored to meet the engine's drive cycle conditions, including load and  
speed.

BACKGROUND OF INVENTION

20 [0003] Both petroleum refineries and engine manufacturers are constantly faced  
with the challenge of continually improving their products to meet increasingly  
severe governmental efficiency and emission requirements, and consumers' desires  
for enhanced performance. For example, in producing a fuel suitable for use in an  
internal combustion engine, petroleum producers blend a plurality of hydrocarbon  
25 containing streams to produce a product that will meet governmental combustion  
emission regulations and the engine manufacturers performance fuel criteria, such  
as Research Octane Number, or RON. Similarly, engine manufacturers  
conventionally design spark ignition type internal combustion engines around the  
properties of the fuel. For example, engine manufacturers endeavor to inhibit to the  
30 maximum extent possible the phenomenon of auto-ignition which typically results

in knocking and, potentially engine damage, when a fuel with insufficient knock-resistance is combusted in the engine.

[0004] Under typical driving situations, engines operate under a wide range of  
5 conditions depending on many factors including ambient conditions (air  
temperature, humidity, etc.), vehicle load, speed, rate of acceleration, and the like.  
Engine manufacturers and fuel blenders have to design products which perform  
well under virtually all such diverse conditions. This requires compromise, as often  
10 times fuel properties or engine parameters that are desirable under certain  
speed/load conditions prove detrimental to overall performance at other speed/load  
conditions. Conventionally, vehicular fuels are supplied in two or three grades,  
typically distinguished by their Research Octane Number, or RON. Generally, the  
selection of fuel grade is based upon the engine specifications. However, once the  
fuel is "on board", it becomes a "one fuel fits all" and must be designed to  
15 accommodate diverse speed, load and other driving conditions.

[0005] One object of this invention is to employ a fuel supply system using a  
membrane for segregating octane boosting constituents from a main fuel tank or  
reservoir, then admixing the segregated fuel to the main fuel supply in response to  
20 engine drive cycle conditions.

[0006] Another object of this invention to establish a procedure for providing  
an engine with fuels specifically designed to enhance engine performance at low  
and high load engine conditions from a single fuel delivered to the vehicle.  
25

[0007] Also, spark ignition engines are generally designed to operate at a  
compression ratio (CR) of 10:1 or lower to prevent knocking at high load.  
Compression Ratio (CR) is defined as the volume of the cylinder and combustion  
chamber when the piston is at Bottom Dead Center (BDC) divided by the volume

when the piston is at Top Dead Center (TDC). As is known, higher CRs, up to about 18:1, are optimum from the standpoint of maximizing the engine thermal efficiency across the load range. A higher CR leads to greater thermal efficiency by maximizing the work obtainable from the theoretical Otto (engine  
5 compression/expansion) cycle. Higher CRs also lead to increased burn rates, giving a further improvement in thermal efficiency by creating a closer approach to this ideal Otto cycle. The use of high compression ratio spark ignition engines, however, is limited by insufficiently high fuel octane, as in practice it is difficult to supply a single fuel with sufficiently high octane overall to allow for a significant  
10 increase in compression ratio without having engine knocking at high loads.

[0008] Therefore, another objective of this invention is to facilitate the use of high compression ratio engines that realize greater thermal efficiency across the entire driving cycle without the problem of knocking at high load by supplying a  
15 specifically formulated fuel derived from the fuel supplied to the vehicle.

[0009] In theory, higher efficiency engine operation at certain moderate to high loads can be achieved by adjusting the spark ignition timing closer to the value that provides minimum spark advance for best torque or maximum brake torque (MBT).  
20 Experience has shown, however, that adjusting the ignition timing to allow MBT to be reached is not practical since knocking typically occurs under conditions of moderate to high load at timings earlier than MBT with commercially available gasolines. In principle, operating with a very high octane fuel would allow running the engine at MBT across the drive cycle. However, a preferred approach is to  
25 supply the engine with a fuel that has sufficient octane to approach or operate at MBT without knocking, together with other combustion properties tailored to optimize performance. The fuel supply system taught herein separates or extracts constituents of the supply fuel that have or can impart sufficient octane to approach or operate at MBT under varied engine load conditions.

[0010] Yet another object of the invention is to provide fuel compositions that allow adjusting the spark ignition timing closer to that which provides MBT.

5 [0011] Presently spark ignition engines are capable of operating with known fuels at a normalized fuel to air ratio (" $\phi$ ") below 1.0 under low to moderate load conditions. The normalized fuel to air ratio is the actual fuel to air ratio divided by the stoichiometric fuel to air ratio. In addition, these engines can be operated with exhaust gas recycle (EGR), as the "leaning out" diluent, at a  $\phi$  of 1.0 or lower. EGR  
10 is understood to include both recycled exhaust gases as well as residual combustion gases. An obstacle to operating the engine under such lean conditions is the difficulty of establishing a rapid and complete burn of the fuel.

[0012] Another object of this invention therefore is to provide a lower octane,  
15 lower autoignition resistant, higher laminar flame speed, high burn rate fuel for use under lean conditions to shorten the burn duration and thereby improve the thermodynamic efficiency. A faster burn rate also serves to maximize conversion of the fuel, thereby increasing the overall fuel economy and reducing emissions. As known in the art, autoignition of the fuel at sufficiently high loads can pose a threat  
20 of mechanical damage to the engine, i.e., knocking. However, at certain low load conditions, for example lean stratified operation, autoignition of the fuel can be beneficial to overall engine operation by optimizing burn characteristics that result in reduced engine emissions and higher efficiency.

25 [0013] The membrane separation or segregation process entails contacting a surface of the membrane with the feed material. Membrane composition is selected to permeate specific constituents of the feed. Those constituents dissolve onto and into the membrane surface region. These constituents then diffuse or migrate to the opposite surface of the membrane.

[0014] Other objects of the invention and their attendant advantages will be apparent from the reading of this specification.

5 SUMMARY OF INVENTION

[0015] One aspect of the invention is a system for separating or segregating fuel constituents from the primary fuel tank of a vehicle to supply particularly formulated fuel to meet engine needs under varying drive cycle conditions. An  
10 objective of the invention is the provision of a plurality of unleaded fuel compositions separated or segregated from a single fuel supply or reservoir, for use in operating a spark ignition, internal combustion engine, especially an engine having a CR of 11 or more, each of which compositions have different predetermined combustion properties suitable for use under preselected engine  
15 operating conditions to improve one or more of fuel efficiency and combustion emissions. The invention uses a membrane to separate an aromatics rich fuel from the fuel contained in the primary tank or reservoir. The membrane functions to preferentially separate aromatic permeate from the remaining retentate. The high aromatic content permeate provides a source of increased RON fuel that is  
20 selectively admixed or run separately to the engine fuel supply at high and moderate engine load conditions.

[0016] In one embodiment a pervaporation membrane process is employed to segregate at least a first and second fuel composition from a single fuel tank, the  
25 first fuel having combustion properties sufficient to improve combustion thereof (relative to the original tank fuel) under high and moderate engine load conditions and the second fuel having combustion properties sufficient to operate the engine under low engine load conditions.

[0017] The pervaporation process, as generally known in the art, relies upon vacuum on the permeate side of the membrane to evaporate the permeate from the surface of the membrane. The vapor phase permeate may then be condensed to liquid form.

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[0018] Especially preferred fuels for use under low load conditions are those unleaded fuels boiling in the gasoline boiling range that have a RON less than 90 and an average burn rate in the engine, defined as 1/ crank angles for 90% burn completion, >105% of isooctane at this time in the engine operating cycle and a  
10 laminar flame speed > 105% of isooctane measured at a temperature and pressure representative of conditions in the engine at or about this time in the engine operating cycle.

[0019] Especially preferred fuels for use under high load conditions are those  
15 unleaded fuels boiling in the gasoline boiling range that have a RON greater than 100 and an average burn rate in the engine, defined as 1/ crank angles for 90% burn completion, >105%% of isooctane at this time in the cycle and a laminar flame speed > 105%% of isooctane measured at a temperature and pressure representative of conditions engine at or about this time in the engine operating  
20 cycle.

[0020] In view of the foregoing it will be readily appreciated that a wide range of modifications and variations of the invention are within the broad aspects set forth above and the unique scope of the invention will become even more apparent  
25 upon a reading of the detailed description which follows.

#### BRIEF DESCRIPTION OF DRAWINGS

[0021] Figure 1 illustrates a fuel separation system of the invention.

[0022] Figure 2 illustrates a membrane fuel separation system of the invention.

5 DETAILED DESCRIPTION OF INVENTION

[0023] As is well known in the art, gasoline fuels generally are composed of a mixture of hydrocarbons boiling at atmospheric pressure in the range of about 77°F (25°C) to about 437°F (225°C). Typically gasoline fuels comprise a major amount  
10 of a mixture of paraffins, cycloparaffins, olefins and aromatics, and lesser, or minor amounts of additives including oxygenates, detergents, dyes, corrosion inhibitors and the like. Typically also, gasoline fuels are formulated to have a RON of about 98 for premium grade and about 92 for regular grade and are used alone in a vehicle engine; the grade used normally depending upon the vehicle manufacturer's  
15 recommendation.

[0024] The present invention departs from the practice of formulating a single fuel for a specific vehicle engine. Indeed, the present invention is based on the discovery that significant benefits can be achieved by providing a range of fuel  
20 compositions having combustion properties tailored to the engine's specific operating condition, and the means to supply the particularly formulated fuel composition with the vehicle having a single supply fuel.

[0025] The fuel compositions of the invention are unleaded fuels boiling in the gasoline range and capable of being used in port or direct fuel injection, spark  
25 ignition, internal combustion engines especially those having a CR of 11 or higher.

[0026] In one embodiment the fuel compositions will comprise at least one first fuel and a second fuel. The first fuel will have a RON greater than 100, and a burn



rate greater than 105% of isooctane at the high load end of the cycle and a laminar flame speed of greater than 105 % of isooctane measured at a temperature and pressure representative of conditions in the engine at the high end of the load scale. The second fuel will have a RON less than 90, a burn rate greater than 105% of isooctane at the low end of the cycle and a laminar flame speed greater than 105% of isooctane measured at a temperature and pressure representative of conditions in the engine at the low end of the load scale.

[0027] The laminar flame speed of the fuel compositions is measured by combustion-bomb techniques that are well known in the art. See, for example, M. Metghalchi and J. C. Keck, Combustion and Flame, 38:143-154 (1980).

[0028] A particularly useful unleaded second fuel for operating the engine in the low load portion of the drive cycle comprises a mixture of hydrocarbons boiling in the gasoline range having an RON < 90 and containing less aromatics than the first fuel, for example, less than about 45 vol.% aromatics and preferably less than 20 vol.%.

[0029] A particularly useful unleaded fuel for operating the engine in the high load portion of the drive cycle comprises a mixture of hydrocarbons boiling in the gasoline range with an RON > 100 and containing greater than about 45 vol.% aromatics and preferably greater than about 55 vol.%.

[0030] Fuels meeting the foregoing characteristics provide efficiency benefits for various types of spark ignited internal combustion engines when operating under high load conditions. High load conditions are defined as being those regions of the engine operating map where at MBT spark timing knocking occurs with a gasoline of RON 98. Knocking is defined as autoignition under sufficiently

severe in-cylinder conditions that it results in a detonation that poses a risk of mechanical damage to the engine.

5 [0031] In the case of spark ignition engines, use of fuels having the properties of the first fuel above permits the engine to be designed to operate at a CR of 11 or more and permits advance spark timing closer to that for MBT. These design features enhance overall cycle efficiency, i.e., provide improved fuel economy.

10 [0032] More particularly these benefits are achieved with direct fuel injection engines and especially direct injection, lean burn engine systems, such as stratified charge direct injection systems. Stratified charge is an in-cylinder condition wherein there is an inhomogeneous air:fuel ratio distribution. As is known in the art, "lean burn" engines operate at normalized fuel to air ratios (" $\phi$ ") of below 1.0 and/or with exhaust gas recycle as the "leaning out" diluent, at a  $\phi$  of 1.0 or lower.

15 [0033] Fuels having the combustion properties of the second fuel above are suitable for use especially in the operation of spark ignition engines, included stratified fuel systems, operating under low load conditions with exhaust gas recycle. Low engine load conditions are those regions of the engine operating map at or below which the engine can be operated at MBT timing with a fuel  
20 having a RON of approximately 90 without the condition of knocking as defined above.

25 [0034] Fuels having a range of combustion properties between the first and second fuel offer even more complete tuning of the fuel compositions to engine operating conditions. Indeed, a third fuel composition can be provided having a RON between those of the first and second fuel, and most desirably a burn rate greater than 105% of isooctane at the medium load end of the cycle and most desirably a laminar flame speed of greater than 105 % of isooctane measured at a

temperature and pressure representative of conditions in the engine at the medium end of the load scale. Such a fuel can be used under moderate engine load conditions, i.e., conditions between high and low load conditions.

5 [0035] The above described fuels are supplied by a fuel system that utilizes a membrane and a pervaporation process to segregate RON and octane boosting constituents from an on-board fuel supply, then selectively admixing the relatively high RON/octane fuel to the regular engine fuel supply responsive to engine drive cycle conditions. This is best illustrated by references to the figure, wherein figure 10 1 depicts an on-board fuel separation system, as taught in the present invention. In figure 1, fuel tank 10 serves as a primary fuel supply source. Conventionally, fuel tank 10 stores and supplies gasoline, whose RON may range from 92 for "regular" grade fuel, to 98 for premium grade fuel. Fuel is supplied from the fuel tank 10 to the membrane apparatus 20. The membrane material, illustrated by 22, is chosen to 15 selectively permeate relatively high RON and octane constituents of gasoline, including for example those constituents of gasoline ordinarily referred to as "aromatics". The permeate constituents segregated by the membrane apparatus 20 are supplied to a high octane accumulator 30, while the retentate is supplied to a low octane accumulator 40. In accordance with one aspect of this invention, engine 20 drive cycle conditions including load (measured in torque), speed (measured in revolutions per minute), spark advance (measured in degrees before or after top dead center, i.e., BTDC or ATDC), intake manifold and exhaust manifold temperature and pressure, knock sensor response, and other engine driving cycle conditions are monitored by sensing system depicted by 50. An admix controller, 25 responsive to the engine drive cycle conditions selectively operates a mixing valve 62 to deliver fuel from the low octane accumulator, the high octane accumulator, or a mixture thereof. The separated or admixed fuel is supplied to an engine fuel injection system depicted at 70.

[0036] The invention employs a membrane pervaporation process and particularly selected membrane to segregate high-octane fuel constituents from primary fuel. Accordingly, membrane 22 is selected from membrane materials to include the following preferable characteristics:

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- i. permeance to selected constituents of gasoline, particular those having RON and octane boosting properties (e.g. aromatics)
- ii. capable of withstanding temperatures as high as 250°C.
- iii. capable of withstanding pressure differentials, when supported, as

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great as 200 bar.

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Suitable membranes include preferably copolymers comprising diepoxide crosslinked/esterified polyimide-aliphatic polyester copolymers such as polyimide/polysuccinate, polyimide/polymalonate, polyimide/polyoxalate and polyimide/polyglutarate and supported composite based membranes using these or appropriate other selective layers; and a variety of other polymeric structures, both crosslinked and uncrosslinked including cellulosic materials such as cellulose triacetate, poly(vinyl pyrrolidone), poly(2,6,-dimethyl-1,4,-phenylene ether), poly(alkylene terephthalates), poly(aryl ether ketone amide)s, poly(aryl ether ketone)s, poly (aryl ether sulfone)s, poly (aryl ether)s, poly(ether ester ketone), poly(ether imide), poly(phenylene sulfide), poly(ester)s, poly(amide)s, poly(imide)s, polyarylates, polymethylacrylates, polybenzimidazoles, polyolefins, polycarbonates, polycycloolefins, polyester-based thermoplastic elastomers, polyethers, polyacrylonitrile and acrylonitrile copolymers, polystyrene and styrene

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copolymers, thermoplastic elastomers, polyester block copolymers, polyamide block copolymers, polyimide block copolymers, polyurethanes and polyurethane block copolymers, thermoplastic polyolefins, thermoplastic vulcanizates, polybenzimidazole, polyketones, ionomers, and supported composite based membranes using these as selective layers.

[0037] The above described fuels are supplied by a fuel system that utilizes a membrane and a pervaporation process to segregate RON and octane boosting constituents from an on-board fuel supply, then feeding separately or selectively  
5 admixing the relatively high RON/octane fuel to the regular engine fuel supply responsive to engine drive cycle conditions. This is best illustrated by reference to the figures; wherein figure 1 depicts an on-board fuel separation system, as taught in the present invention. In figure 1, fuel tank 10 serves as a primary fuel supply source. Conventionally, fuel tank 10 stores and supplies gasoline, where  
10 RON may range from 90 for "regular" grade fuel, to 98 for premium grade fuel. Fuel is supplied from the fuel tank 10 to the membrane apparatus 20. The membrane material, illustrated by 22, is chosen to selectively permeate relatively high RON and octane constituents of gasoline, including for example those constituents of gasoline ordinarily referred to as "aromatics". The permeate  
15 constituents segregated by the membrane apparatus 20 are supplied to a high octane accumulator, while the retentate is supplied to a low octane accumulator 40. In accordance with one aspect of this invention, engine drive cycle conditions including load (measured in torque), speed (measured in revolutions per minute), spark advance (measured in degrees before or after top dead center,  
20 i.e., BTDC or ATDC), intake manifold and exhaust manifold temperature and pressure, knock sensor response, and other engine during cycle conditions are monitored by sensing means depicted by 50. An admix controller, responsive to the engine drive cycle conditions selectively operates a mixing valve 62 to admix fuel from the high and low octane accumulators. The admixed fuel is supplied  
25 to an engine fuel injection system depicted at 70.

[0038] Referring to Figure 2, there is schematically shown a fuel supply system for supplying two or more fuels having specifically formulated properties. In figure 2, fuel tank 10 stores and supplies conventional fuel such as

gasoline. A fuel pump 12 may be used to pump at increased pressure to the membrane apparatus 20. As detailed hereinafter, operation of membrane 22 may be improved by pressurization of the fuel contacting the membrane on the retentate side, here shown at 24. Accordingly, fuel pump 12 may be utilized to  
5 supply pressurized fuel to the membrane apparatus 20 at pressures ranging from about 1.5 to 20 bar and preferably from about 2 to 10 bar. A flow control means 14 may be used to control or regulate the fuel flow from the fuel tank 10 to the membrane apparatus 20.

10 [0039] As further detailed below, the functioning of membrane 22 is influenced by the temperature of the membrane, which may be preferentially heated to improve or control the permeation rate through the membrane. Therefore, in a preferred embodiment a heater 16 is provided to heat the fuel and membrane apparatus 20 providing sufficient sensible heat to maintain the membrane at the  
15 desired outlet temperature, while providing the heat need for vaporization of the permeate.

[0040] Retentate 24 from the membrane apparatus 20 may be cooled by means of a heat exchanger 25a. Cooling of the retentate 24 may be advantageously made  
20 by heat exchange against the ambient fuel 10 flowing to the heater 16. This also serves to preheat the fuel to the heater 16. As stated above, the pervaporation process relies upon a vacuum on the permeate side of the membrane, here shown as 26, to help drive the membrane process. Accordingly, a vacuum pump 27 and optimal vacuum pump regulator valve 28 may be used to provide a vacuum to the  
25 permeate side of the membrane, here shown as 26. The vacuum maintained on the permeate side of the membrane may range from about 0.05 bar to about 0.9 bar, preferably from about 0.05 bar to about 0.5 bar.

[0041] In one embodiment, membrane 22 comprises a polyamide/polyadiapate membrane selected to preferentially permeate aromatic constituents of gasoline. The gasoline, comprising conventional "regular grade" 92 RON having less than or equal to about 35% aromatic content, is separated into a first high octane/RON fuel having up to about sixty-five percent (65%) aromatic content and a RON in excess of about 100 RON. The second or retentate fuel has a RON ranging from about 80 to about 85.

[0042] The permeate from membrane 26 is vaporized upon departing the membrane 22. To return the vapor permeate to a liquid form, condensing means 29 may comprise a cooling device such as a compact heat exchanger using ambient air as the cooling media. The permeate, now in predominately liquid form, is supplied to the high octane accumulator 30. A pump means control valve 29 may be utilized to supply the condensed permeate fuel to the high octane accumulator. A fill sensing device 31 may be used to identify when the high octane accumulator is filled, and function to either reduce the volume of permeate through the membrane, return amounts of the high octane permeate to the fuel tank 10 or a combination thereof.

[0043] The retentate low RON fuel leaving the membrane apparatus 20 is supplied to the low RON accumulator 40.

[0044] As described above, the high RON fuel is admixed to the low RON fuel at 62 whenever engine drive cycle needs require fuel whose RON or octane requirements are higher than that supplied by the second or retentate fuel from low RON accumulator 40.